FORMAL AIDS TO MODEL FORMULATION USING WORTH ASSESSMENT AND DELPHI

Fahriye H. Sancar, Department of Landscape Architecture, University of Wisconsin
Bulent Ozgul, Department of Industrial Engineering, Middle East Technical University, Ankara, Turkey

Fahriye H. Sancar. After completing Ph.D. studies in Dept. of Man-Environment Relations, Pennsylvania State University (USA), has worked as a research associate in the Operations Research Division of the Marmara Scientific and Industrial Research Institute in Instanbul (Turkey), as assistant professor in the Department of Operational Research and Statistics, Middle East Technical University in Ankara (Turkey) and principle investigator in the System Sciences Research Institute, M.E.T.U., Ankara (Turkey). Currently she is on leave at the Department of Landscape Architecture, School of Natural Resources, University of Wisconsin, Madison, Wisconsin, USA. Major research and teaching interests lie in the area of problem solving methods for socio-economic and environmental planning.

Bulent Ozgul is a graduate student in the Department of Industrial Engineering, Middle East Technical University, Ankara, Turkey. Major interest is computer simulation techniques for modeling industrial and social systems.

ABSTRACT

This paper deals with the application of System Dynamics to user participation in departmental policy making in a university. A systematic method for the estimation of multipliers using worth assessment and delphi techniques is discussed. Expected behavioral responses of the users to changes in the major state variables are incorporated into a simulation model.

1. INTRODUCTION

The conception of planning as a social learning process has found support among planners. Within this framework, it is also argued that social learning to enhance systems adaptation can be effectively achieved through "collective decision-making."

A problem solving process can be characterized as "collective decision-making" provided certain criteria are satisfied. The major requirement is that all parties affected by the problem and/or its solution have to participate in the design and implementation of the planning experiment. All the interests and latent preferences relevant to the problem have to be systematically considered. Equal opportunity for all parties to originate/propagate and implement ideas should be ensured.

Such a decision-making process should also contribute to the individual's knowledge of the problem by following an iterative procedure allowing crystallization of opinions, recognition of interests and formulation of alternative solutions. The process should then test these alternatives and evaluate itself at various stages, leading to possible modifications in participant constituency, problem conceptualization and the projected goals.

To satisfy these criteria, the planner is required to employ an array of techniques to synthesize the knowledge, experience and preferences of all the participants to construct a formal decision model. This synthesis is invariably characterized by combined use of objective or empirical, and subjective or judgemental types of data. As such the incorporation of the data into decision models still remains to be the crucial issue for a realistic representation of any problem situation.

An operational model encompassing the major requirements for a collective decision making process can be constructed as shown in Figure 1[1]. In reviewing the salient features of the model, Policy Delphi[2] is found to be most appropriate for the initial structuring of the situation (i.e. problem documentation) where major interest groups, relevant issues and conceived policy alternatives are identified. The information obtained via iterative application of the policy delphi is used to prepare the problem scenario, providing the basis for the formal model with its global system boundaries, subsystems and their relationships.

Figure 1: An Operational Model for Collective Planning

The modeling technique used in formulation and operationalization is dynamic simulation. This choice is prompted by the capabilities of the technique in effectively representing interdependencies among relevant variables and the dynamic nature

of the phenomena; in conceptualization of the system in terms of non-linear feedback relations; allowing for the incorporation of empirical as well as judgemental data, and its potential as a decision-making medium for the general public.

The model operation phase is the completion of the process via provision of the necessary quantitative data in the form of system constants, initial values of variables and multiplier functions. Subsequent simulation experiments, within a gaming context, are then carried out to refine and test alternative solutions. Delphi techniques, frequently used for self-evaluation by groups, are used for the overall evaluation of the model and of the "learning process".

The operational model for collective decision-making as described above was implemented using the DYNAMO formalism in two different planning problems; downtown revitalization[1,3] and university planning[4]. In both studies, techniques for incorporating user-generated data into the simulation model are extensively explored; particularly in specifying model components and quantification of system relationships. In the first study, a systematic technique is developed to structure the system and estimate the multipliers exclusively from consumer preference questionnaire-surveys. In the second study, the same technique is further modified implementing worth assessment and Delphi procedures.

In this paper, we focus on the general issue of using empirical data in system dynamics formulations and illustrate the application of the above mentioned multiplier estimation technique within the framework of the present model and of the case study referred to as the "departmental policy making in a university". As the main objective is to present the estimation procedure, details of the total model and the results of the simulations will be omitted.

II. USE OF EMPIRICAL DATA IN SYSTEM DYNAMICS FORMULATIONS

A major criticism of the System Dynamics approach has been the lack of empirical support for the functional relations that are taken to be the basis for the model[5]. Discussions concerning this problem are focused on two different but related issues consisting of the applicability of conventional statistical estimation techniques and the arbitrariness of the multiplier functions[6].

Counterarguments to the limited use of statistical data and estimation techniques in model formulation have been well founded. It has been shown that[7] the system dynamics models are generally insensitive to parameter changes. Since the accuracy required in parameter estimation can only be determined after the model has been run, a precise initial estimate is superfluous.[8,9] Furthermore the applicability of standard statistical techniques to non-linear state-variable systems is questionable due to both conceptual and methodological difficulties.[10] A functional relationship describing a presently non-existing situation (such as the effect of a new policy on state variables) can not be verified using past data. These considerations indicate that standard estimation techniques can at best play a minor role in model formulation.

The response to the issue of arbitrariness of the multipliers has been to ensure credibility by post-formulation evaluation

via validation of the *whole* model or verification of the parameters. It has been argued that[11, 12] model validation is possible by comparing the behavior of the simulated system with the actual system using historic data. The agreement between the two can then be presented as evidence for acceptability of both the functional forms and the parameters of the multipliers.

In the parameter verification approach, model parameters are compared with their counterparts in the real system to determine the existence of a conceptual and numerical agreement.[13] Both approaches offer partial solution to the problem by suggesting validation procedures after the parameters are specified. Thus due to the inapplicability of statistical estimation techniques and lack of rigorous validation procedures, the mode of construction of the multipliers in System Dynamics formulation has remained arbitrary with the exception of a few studies implementing survey type techniques.

In their study of recreational planning in Lake Tahoe Basin[14], Arnold, et. al. proposed that if the policymakers' hypotheses are used in model formulation, they would be more inclined to accept the results of the model. In their study, participant opinions are directly incorporated into analytical multiplier functions with adjustable parameters. These parameters are determined using an iterative quazilinearization analysis of responses to surveys in questionnaire format, closely resembling that of a policy delphi.

In another study on downtown revitalization planning[1,3], multiplier functions are estimated exclusively from consumer preference surveys. It was observed that due to remarkable regularity of public preferences, the responses to all issues could be represented by standard normalized Beta density functions typically used to describe distribution of expected utilities. The technique is noted to be particularly useful in determining multiplier functions when the opinions of a large number of people are to be synthesized.

Graham[15], in his discussion of strategies to formalize parameter estimation in system dynamics, has suggested a stepwise procedure where extreme values, slopes and a normal point is specified, and a smooth curve passing through the extreme and normal points is drawn. He does not, however, address the problem of eliciting *reliable* expert response and reconciling and/or combining these responses.

The literature on multiplier estimation indicates that the main issue is not so much to ensure accuracy as it is to propose a *method* ensuring consistency and precision in estimation. In particular, public and expert participation in estimation is an acceptable and more advanced method than the original method of "intuitive" multipliers proposed only by the model builder himself. Participation both in formulation and multiplier estimation is expected to enhance the correspondence between the real system and the model, the user understanding of the problem situation and their confidence in the model.

In the following sections we give a brief overview of a departmental policy making model to provide the context and illustrate the proposed participatory multiplier estimation technique for a selected subsystem sector.

III. THE PROBLEM CONTEXT AND THE MODEL

The departmental policy making model was developed to aid the decision-makers and other interested parties in understanding and resolving the problem of mass departure of academic staff and the consequent decline in educational quality due to external pressures to increase admission capacity in a state university. The main objective was to develop a process enabling user groups to propose and verify a model structure reflecting their perception of their own behavior.

In this context, the university and its departments are represented by the student, faculty, administration/services and the physical facilities subsystems with several relevant sectors. These sectors and the main interactions are shown in Figure 2. Since the faculty subsystem is identified as the most critical from policy standpoint, and related multipliers represent intangible relations concerning faculty responses to changes in system performance, this subsystem is chosen for the estimation example.
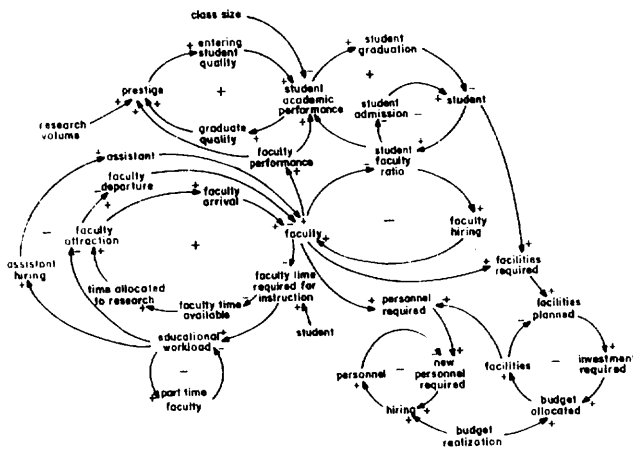

Figure 3: Flowchart of the Faculty Sector

Figure 2: Causal Loop Diagram of Policy Making in a University

This particular subsystem is modeled to reflect the dynamics of teaching, research, and academic administration consisting of faculty and assistant sectors, and a sector representing the allocation of faculty time. A typical faculty sector is shown in Figure 3 where the level and rate variables are illustrated with rectangles and valves respectively. Circles are the auxillary variables used in formulating the rates of flow.

The rates of flow in the faculty sector are influenced by a "departmental attractiveness" multiplier which is defined to represent the characteristics influencing an academician's preference to accept and continue to work in a department and consequently in the university. Its components are research opportunity, educational workload, salary and student quality input multipliers expressed as table functions and are combined multiplicatively to determine the overall attractiveness.
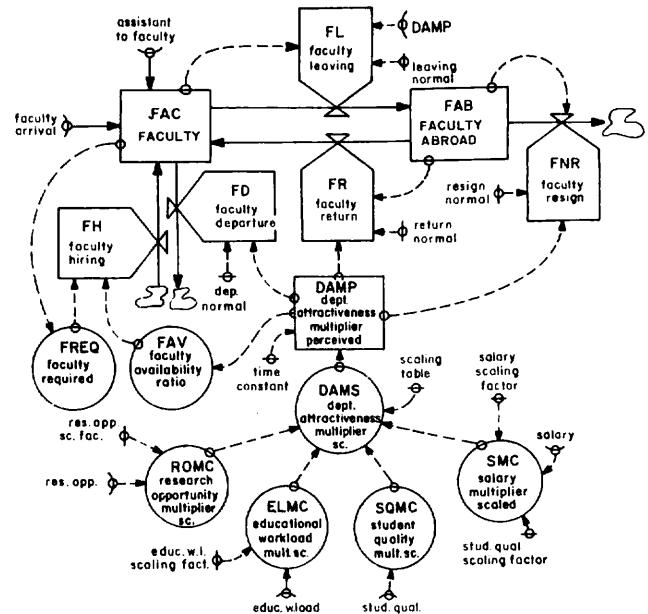
IV. MULTIPLIER ESTIMATION USING WORTH ASSESSMENT AND DELPHI

In this study worth assessment and delphi procedures are combined to construct the multiplier functions. Worth assessment provides a formal methodology to analyze multi-attribute consequences and to establish preference relationships[16] while delphi methodology offers a systematic procedure to combine the opinions of a panel of experts.[17]

Worth assessment is used to subdivide an overall performance attribute (e.g. departmental attractiveness) into lower level attributes (e.g. educational workload, salary, etc.) generating a hierarchical structure by repeated application of the process at each lower level. The process is continued until it is felt that the overall performance attribute has been defined in sufficient detail to be measured. The connection between the physical measure and the attribute is then determined by selecting a performance measure and specifying its "scoring function". This function is the mathematical rule assigning a worth score to all possible values of a given performance measure.

The impact of the lower level attributes on the overall attribute is ascertained by allowing the participants to rank the subattributes according to the relative importance of their effects on the overall attribute by assigning point scores to each subattribute. These scores are then used to calculate the weighting function of each subattribute by normalizing with the highest score in a given set. The product of sub-attribute weights provides a value for the overall attribute. These results are further scaled such that the maximum and minimum of the function as obtained from the user-generated data are not exceeded.

In the present study, the above procedure is implemented by addressing a delphi inquiry to all members of the faculty to determine the previously explained scoring functions, sub-attribute weights and the extrema of the overall attributes.

The questionnaires are designed to define three main attributes named as faculty attractiveness, student academic performance and departmental prestige. For each of these, a set of lower level attributes are presented and the participants are asked to assign relative-importance point scores to each of the subattributes and estimate the extrema of the corresponding overall attribute, as compared to its present value of unity. Subjective evaluations of faculty on changes in various performance measures are also asked to obtain the sub-attribute scoring functions which are referred to as multipliers. Present level of the performance measure is also taken to be unity.

In a second-round follow-up inquiry initial responses are fed back to each participant in the form of medians, quartiles, extreme opinions obtained from the previous round together with the particular individual's own responses. The respondent is then asked to re-evaluate his answer and briefly explain his modified point of view if his new answer is outside the first and third quartiles. Two rounds were sufficient to obtain conformity within a prescribed range.

V. AN EXAMPLE OF THE ESTIMATION PROCEDURE

The example chosen is the determination of a "departmental attractiveness" multiplier defined by the participants to indicate the willingness of a professor to work in the department. The lower level attributes associated with the multiplier are taken to be research opportunity, teaching workload, salary and student quality.

To determine the relative importance of the effects of the lower level attributes on the overall attractiveness the faculty is asked to:

> . . . Indicate the relative importance of each factor on the attractiveness of the department by distributing 100 points among them.

and in the second round:

> The estimates of the Relative Importance of each factor on the DEPARTMENTAL ATTRACTIVENESS are shown in the graph below. For each factor the region
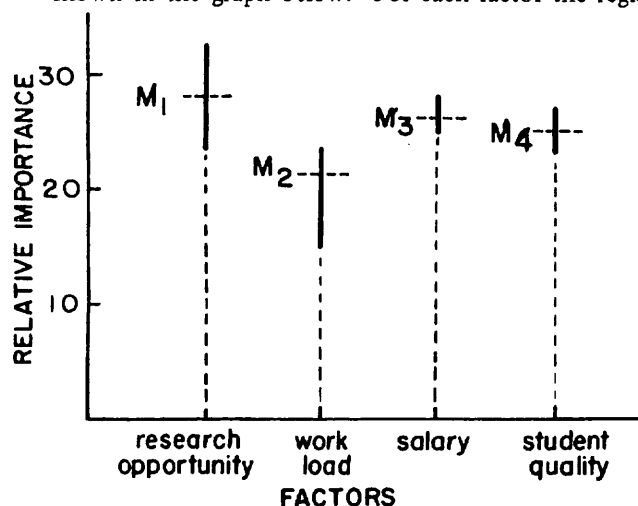

Figure 4: Relative Importance of the Effects of Subattributes (Factors) on the Overall Attribute "Departmental Attractiveness"

involving the estimates between the first and the third quartile are shown by a bar. Also the mean of the estimates and your own estimate are marked.

> Re-evaluate your estimate by distributing 100 points among the factors according to their relative importance on Departmental Attractiveness. If your estimate falls above or below the bar, explain why your opinion is correct (Fig. 4).

The range of the Overall attribute is determined by asking the following question:

> Assume that the departmental attractiveness can be represented by an index where the present value is equal to unity. What maximum value can this index attain at any ideal set of conditions? Similarly, what is the minimum value of this index under the worst possible conditions?

and in the second round,

> The estimates of the maximum and the minimum values the DEPARTMENTAL ATTRACTIVENESS INDEX can attain — compared to present — are shown in the frequency diagrams below (Fig. 5). *The first quartile, the median and the third quartile are shown and your opinion marked. Re-evaluate your estimates and if your estimates are either smaller than the first quartile or greater than the third quartile, state briefly why your opinion is correct.*
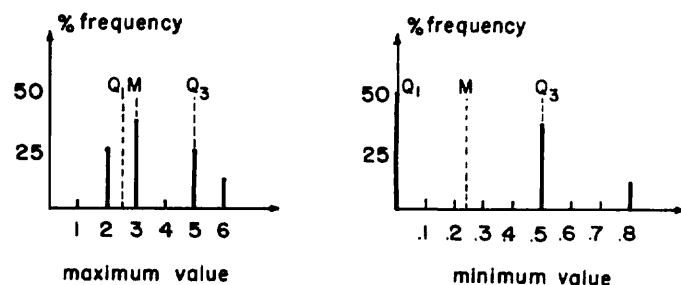

Figure 5: Estimates of the Maximum and Minimum Values of the Departmental Attractiveness Index

Finally, the respondents are asked to estimate how the overall attribute will change as the subattributes increase or decrease compared to their present values:

> Salary is one of the determinants of the desire to work in a university. How would the present attractiveness of the department change with respect to the changes in salary in terms of premiums paid in a year (presently two premiums are given per year)?

	% increase in Attractiveness	% decrease in Attractiveness
— No premiums		
— 4 premiums a year		
— 6 premiums a year		
— 12 premiums a year		

and similarly in the second round:

In this section are shown the estimates on the change in DEPARTMENTAL ATTRACTIVENESS with respect to

changes in various factors (Fig. 6). Also shown are extreme opinions, the curve passing through the medians and your previous estimate. The bars indicate the region which includes the estimates between the first and third quartile. Re-evaluate your estimates. If your new estimates fall above or below the bar, state briefly why your opinion is correct.
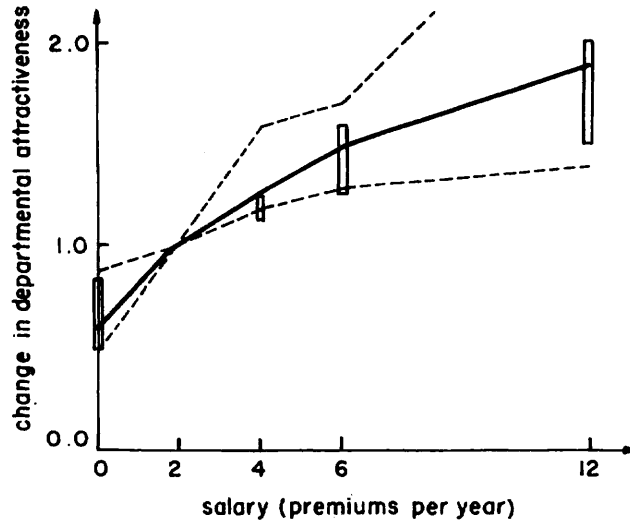

Figure 6: Estimates of Change in Departmental Attractiveness with Respect to Changes in Salary

The scoring functions obtained in the final step above comprise the input multipliers. As an example, salary multiplier (SM) is presented in Figure 7 and Equation 2 below.

$$A \ SM.K = TABLE \ (SMT, SAL.K, 0, 12, 2) \quad (2)$$
$$T \ SMT = .6/1/1.2/1.4/1.5/1.65/1.8 \quad (3)$$

where salary is measured in terms of premiums per year and SMT is the table function corresponding to data in Figure 7.
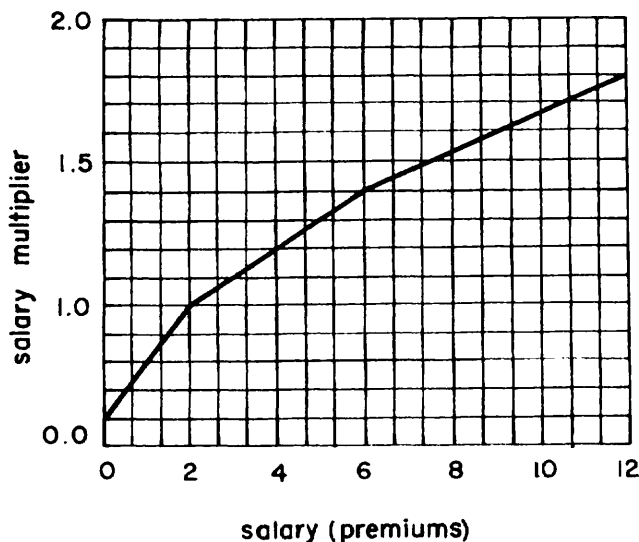

Figure 7: Salary Multiplier

The input multipliers are then scaled by their relative weights obtained in the first step, as shown below.

$$A \ SMC.K = 1 + SSF \ (SM.K-1); SSF = 19 \quad (4)$$
$$A \ ROMC.K = 1 + RSF \ (ROM.K-1); RSF = 1 \quad (5)$$
$$A \ ELMC.K = 1 + ELSF \ (ELM.K-1); ELSF = .75 \quad (6)$$
$$A \ SQMC.K = 1 + SQSF \ (SQM.K-1); SQSF = .9 \quad (7)$$

where SMC, ROMC, ELMC, SQMC are scaled salary, research opportunity, educational workload and student quality multipliers respectively. Similarly the SSF, RSF, ELSF and SQSF are scaling factors (or relative weights) showing the interaction between the input variables.

In this study the relative weights of input variables are assumed to remain constant over the entire range of input and output variables which is not a realistic assumption if the model is allowed to perform outside the ranges specified in the questionnaires. However, if an interactive (gaming) version of DYNAMO is utilized, the scaling factors may be modified at intervals when the values of the input variables are out of range.

The overall attribute multiplier, departmental attractiveness (DAM), is the product of the subattribute functions given in Equations (4) to (7) represented by,

$$A \ DAM.K = SMC.K * ELMC.K * SQMC.K * ROMC.K(8)$$

The rescaling is done by finding the max-min values of the product, DAM, and linearly transforming these extreme values to fall within the max-min range determined by the relevant questions in the second step of the delphi procedure (Equations 9, 10),

$$A \ DAMS.K = TABLE \ (DAMST, DAM.K, 0, 5, 1) \quad (9)$$
$$T \ DAMST = .2/1/1.65/2.25/2.9/3.6 \quad (10)$$

where DAMS is the scaled attractiveness multiplier.

VI. CONCLUSION

In this study a multiplier estimation technique using worth assessment strategy and the delphi procedure has been presented. The main objective of the approach is to incorporate the opinions and preferences of people who are most familiar with the problem and are in a position to influence system behavior, into the modeling process while maintaining consistency and precision.

One major conceptual difficulty in multiplier construction using expert or user input about interactions between model variables is due to the feedback nature of system dynamics models. The user is asked to specify the relation between each of the input variables and an output variable so that each relation is expressed by a single multiplier. Whether the resulting relationship takes the interaction among the rest of the variables into account is not clear. In fact one could argue that individuals differ in their style and ability to perceive relationships. Some may be able to isolate interactions and supply binary relationships whereas some would be considering interactions among the other relevant variables when defining a multiplier.

94

Multiplier estimation using the worth assessment approach provides the participant with a frame of reference by presenting the total scheme of interactions defining an outcome or a decision. Given such a reference frame, specification of a single relationship becomes easier and more meaningful. Then he is asked to follow a systematic procedure where interactions are explicitly taken into account. As all the respondents are guided by the same procedure, the results are expected to be consistent.

When more than one person participates in any stage of modelling, the diverse responses need to be aggregated. The particular method used for this purpose is the delphi procedure. Its main advantages are that effect of dominant individuals is reduced through *anonymity*, the exercise is conducted in a sequence of rounds allowing for *controlled-feedback* of responses and a statistical group response is obtained by reducing group pressure for conformity.[18]

The Delphi procedure becomes particularly appropriate when interactions reflect highly subjective, individualized attitudes concerning the respondents' immediate environment. In this situation maintaining anonymity becomes crucial. In reality attitudes change as the individual goes through a learning process, similar to the controlled feedback in the delphi procedure. Therefore, more reliable information about a group's response is obtained without imposing group pressure on the participants.

REFERENCES

1. SANCAR, F.H., (1977), A model of planning methodology for community participation and urban development, Ph.D. Thesis, Pennsylvania State University.

2. TUROFF, M., (1975), The Policy Delphi, In H.A. Linstone and M. Turoff, The Delphi method, techniques and applications, Addison-Wesley.

3. SANCAR, F.H., (1981), A dynamic simulation formulation based on user preferences, submitted to ORSA-TIMS Conference at Colorado Springs.

4. OZGUL, B., (1981), A system dynamics model for a university department, M.S. Thesis, Middle East Technical University.

5. OHLS, J.C. and HUTCHINSON, P., (1975), Models in urban development, In S.I. Gass and R.L. Sisson (Eds), A guide to models in governmental planning and operations, Sauger Books.

6. LEGASTO, A.A. Jr. and MACIARIELLO, J.A., (1980), System dynamics: A critical review, In A.A. Legasto Jr.,J.W. Forrester and J.M. Lyneis (Eds),System Dynamics, North Holland.

7. SENGE, P., (1977), Statistical estimation of feedback models, Simulation, Vol. 28, No. 6 (June).

8. FORRESTER,J.W.,(1961),Industrial dynamics,MIT Press.

9. FORRESTER, J.W., (1969), Urban dynamics, MIT Press.

10. GOODMAN, M.R. and SENGE, P.M., (1974), Issues of empirical support for the migration formulations in 'Urban Dynamics'. In N.J. Mass (Ed.), Readings in urban dynamics: Vol. I, Wright-Allen Press.

11. SCHRODER, W.W. III and STRONGMAN, J.E., (1974), Adapting urban dynamics to Lowell. In N.J. Mass (Ed.), Readings in urban dynamics: Vol. I, Wright-Allen Press.

12. MASS, N.J., (1974), A dynamic model of land pricing and urban land allocation. In N.J. Mass (Ed.), Readings in urban dynamics: Vol. I, Wright-Allen Press.

13. FORRESTER, J.W. and SENGE, P.M., (1980), Tests for building confidence in system dynamics models, In A.A. Legasto, Jr., J.W. Forrester and T.M. Lyneis (Eds), System Dynamics, North Holland.

14. ARNOLD, W. III, YOUNG, T.W. and BREWER, J.W., (1977), Constructing non-linear dynamic models for socio-environmental decision-making: A Methodology, Institute of Governmental Affairs, University of California, Davis.

15. GRAHAM, A.K., (1980), Parameter estimation in system dynamics modeling, In A.A. Legasto, Jr., J.W. Forrester and J.M. Lyneis (Eds), System Dynamics, North Holland.

16. SAGE, A., (1977), Methodology for Large Scale Systems, McGraw-Hill.

17. LINSTONE, H.A. and TUROFF, M., (1978), The Delphi method, techniques and applications, Addison Wesley.

18. PILL, J., (1981), The Delphi method: Substance, context, a critique and an annotated bibliography, Socio-Economic Planning Sciences, Vol. 5, pp. 57-71.